Advanced In-Space Propulsion Technologies for Exploring the Solar System and Beyond

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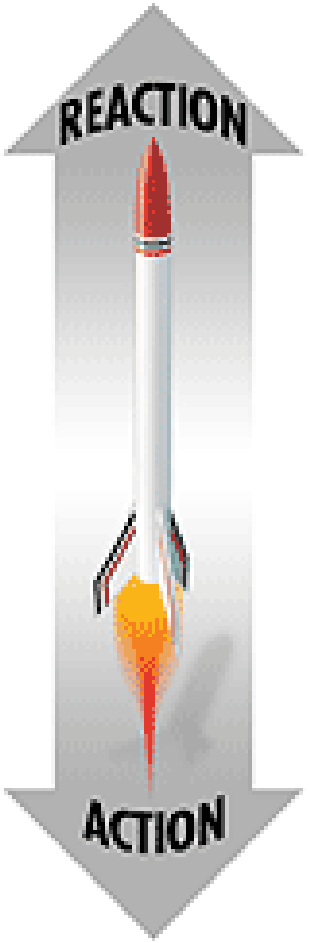
National Aeronautics and Space Administration

NASA

MARSHALL SPACE FLIGHT CENTER

What Is Propulsion?

- **Initiating or changing the motion of a body**
  - ***Translational*** **(linear, moving faster or slower)**
  - ***Rotational*** **(turning about an axis)**
- **Space propulsion**
  - **Rocket launches**
  - **Controlling satellite motion**
  - **Maneuvering spacecraft**



At one time it was believed that rockets could not work in a vacuum -- they needed air to push against!!

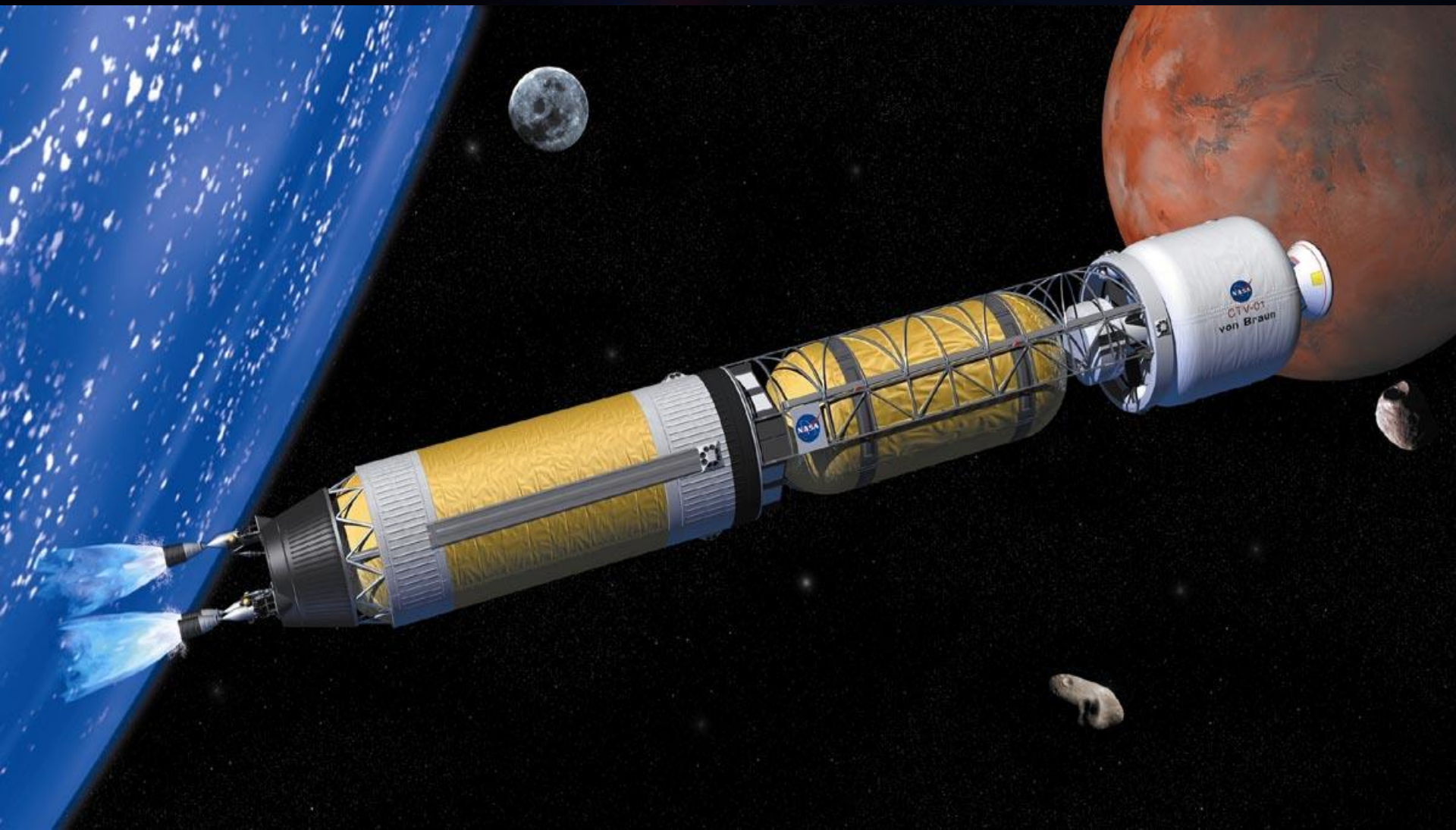
Courtesy of Stephen Hevert

The Big Chemical Rocket Engines…

F-1 Engine
Saturn V
1.5 million lbs thrust (SL)
LOX/Kerosene

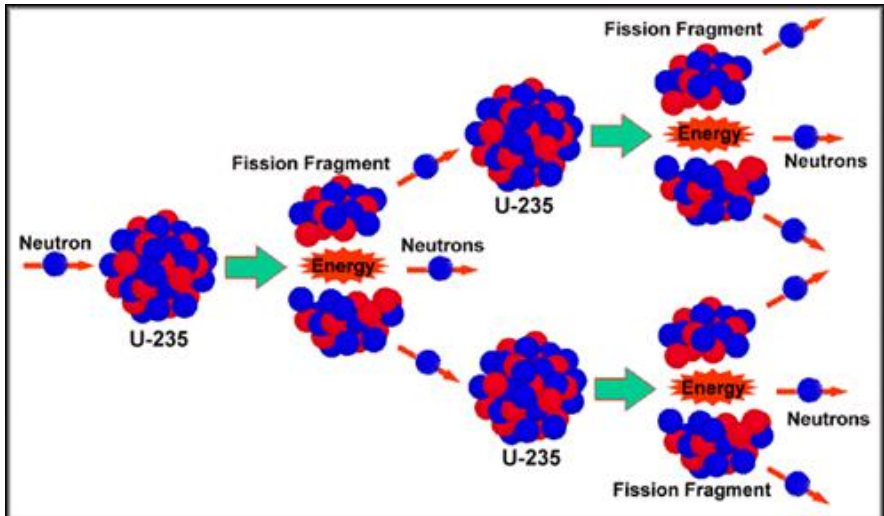
Main Engine
Space Shuttle
374,000 lbs thrust (SL)
LOX/H_2

Nuclear Thermal Propulsion



Nuclear Thermal Propulsion

- System that utilizes a nuclear fission reactor
- Energy released from controlled fission of material is transferred to a propellant gas
- Fission
  - Absorption of neutrons in a fuel material
  - Excitation of nucleus causes fuel atoms to split
    - Two new nuclei on average (Fission Fragments)
    - 1 to 3 free neutrons

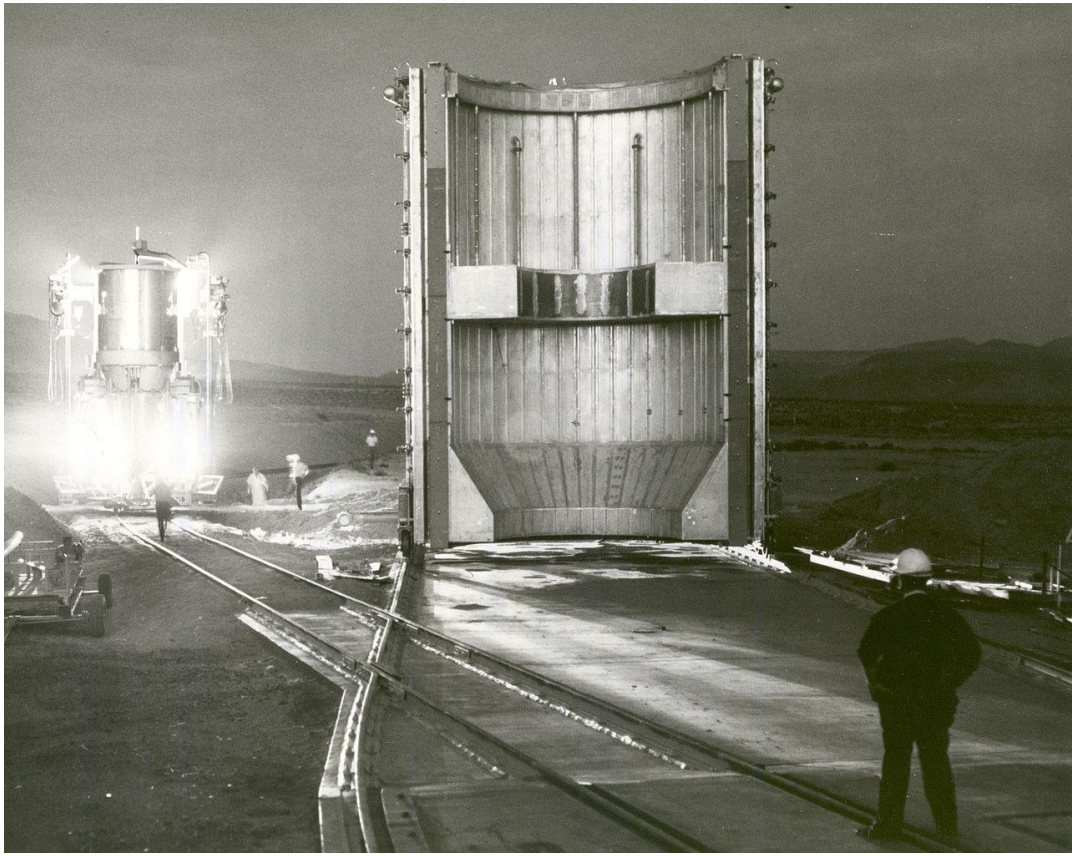


A Nuclear/Chemical Comparison

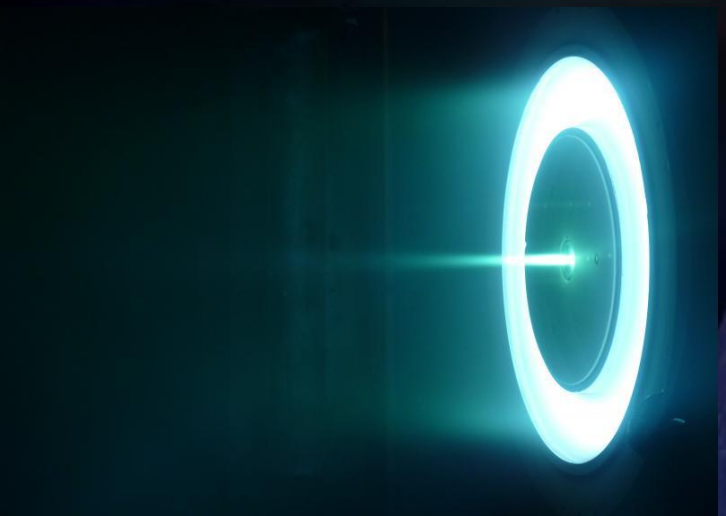
- **One gram** of U-235 can release enough energy during fission to raise the temperature of 66 million gallons of water from 25^{o}C to 100^{o}C.
- By contrast, to accomplish the same sort of feat by burning pure gasoline, it would require **1.65 million gallons of the fuel**

The USA Had a Nuclear Thermal Rocket Engine…

- Nuclear Engine for Rocket Vehicle Applications
  - Power: 300 – 200,000 MW
  - Thrust: 890 kN
  - Isp: 835 sec
  - Hydrogen propellant
- Cancelled in 1972

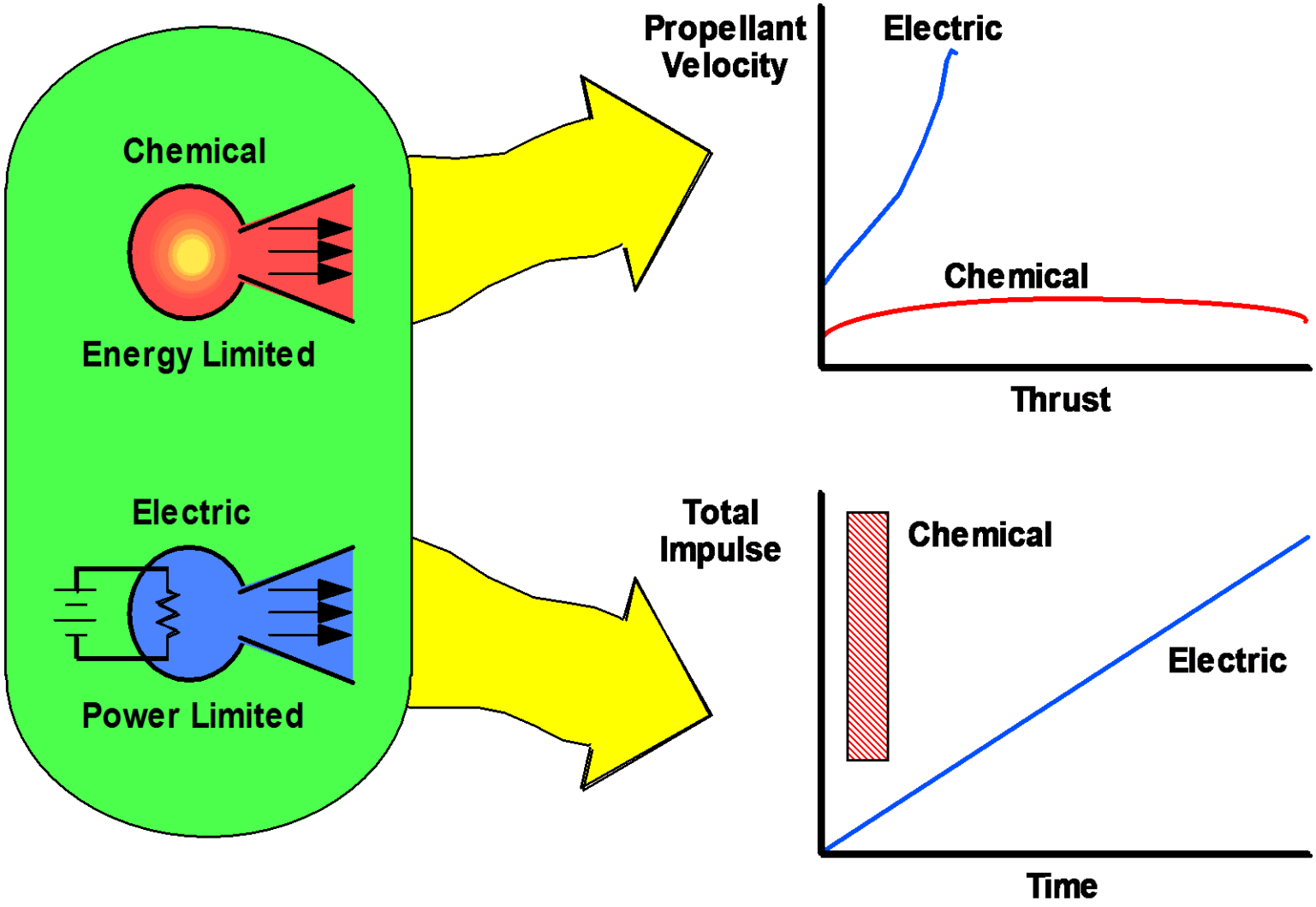


Electric Propulsion

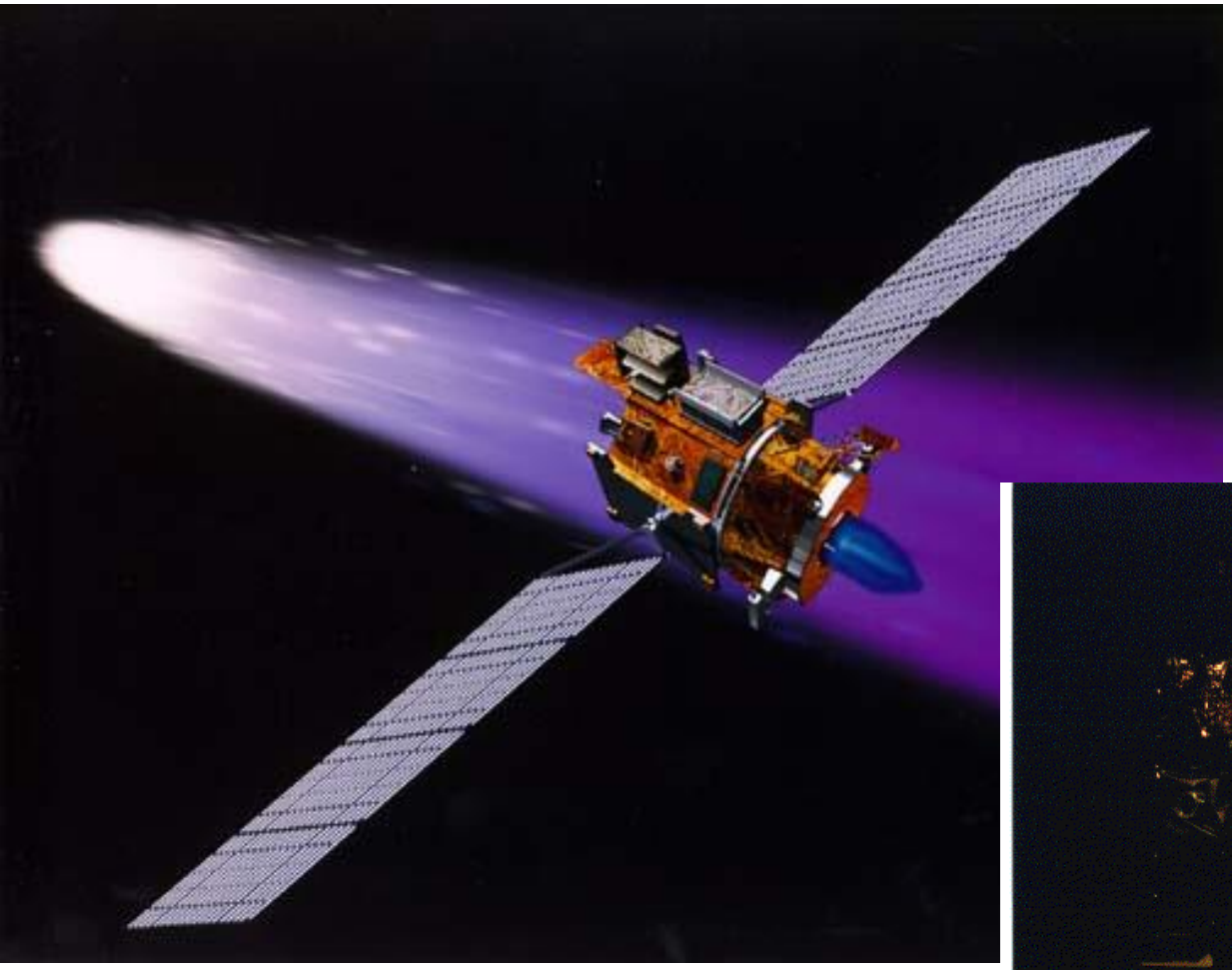


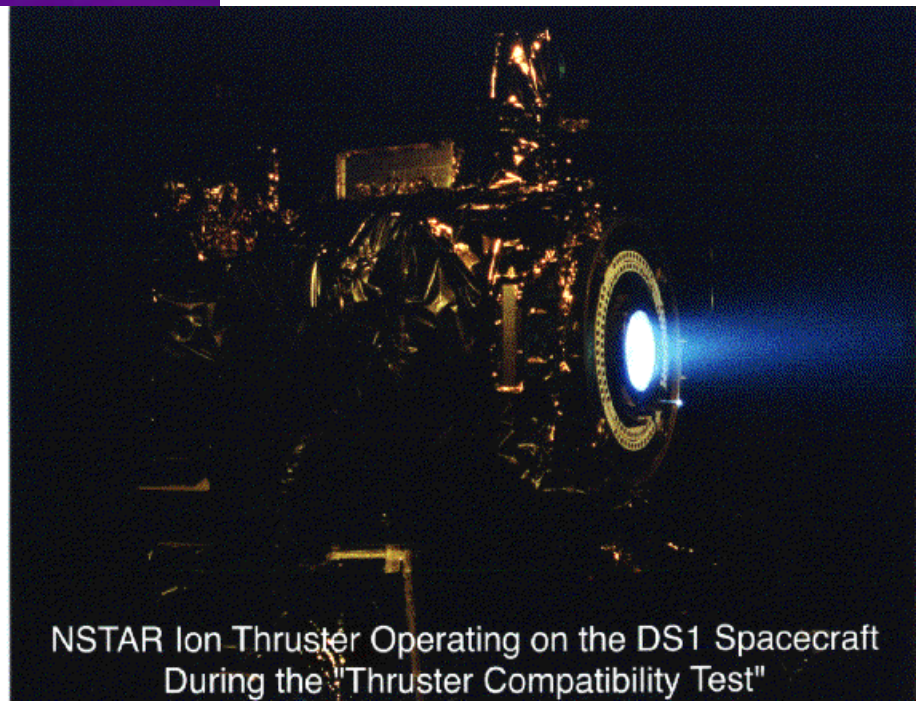
Ion Thruster

Chemical & Electric Propulsion Have Intrinsic Differences



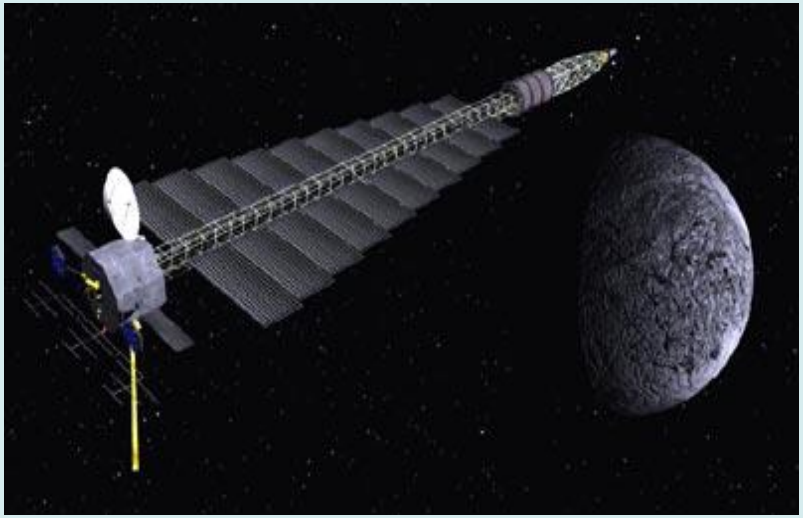
NASA's First Use of SEP For Primary Propulsion: Deep Space 1





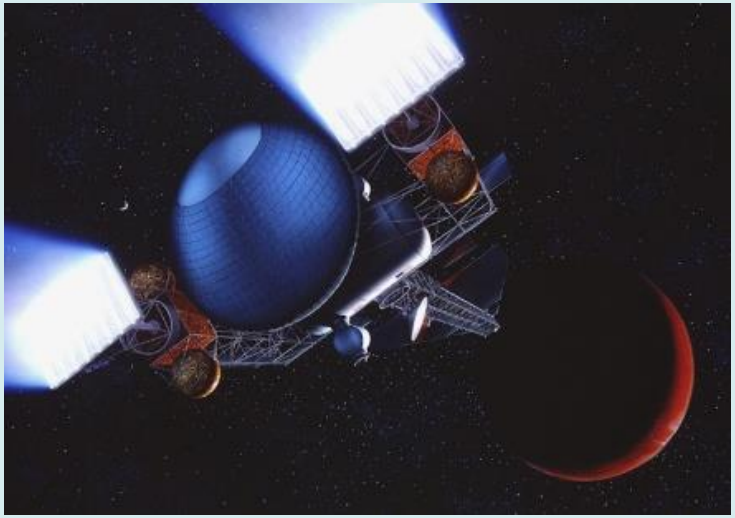
NSTAR Ion Thruster Operating on the DS1 Spacecraft During the "Thruster Compatibility Test"

Evolution of Power for Nuclear Electric Propulsion



Moderate Power NEP-Near Term

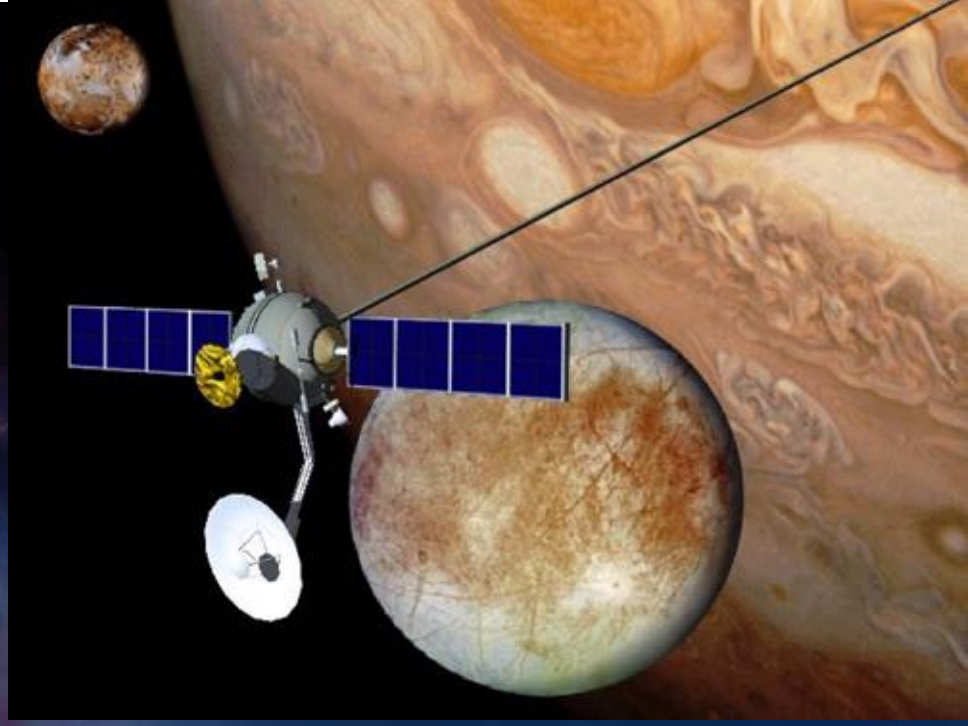
- 100 kWe to 1 MWe
- 1200 K reactor outlet – direct gas Brayton or pumped liquid metal coolant.
- Brayton or Stirling power conversion
- 500 K composite radiators with H_2O heat pipes



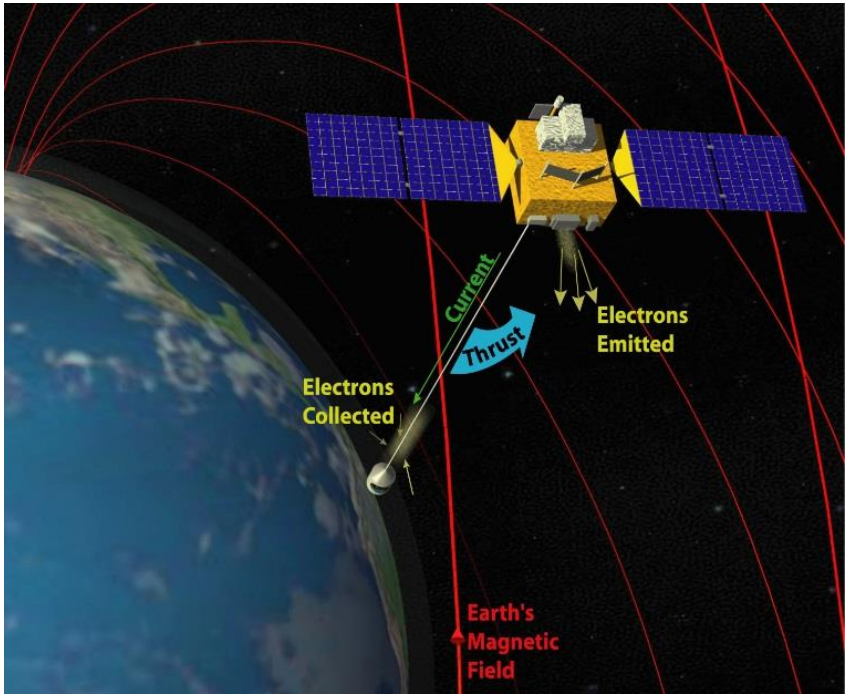
High Power NEP-Far Term

- Multi-Megawatt
- 1500 K Liquid metal (Li) cooled reactor with UN or other advanced fuel and refractory alloy structure
- Brayton or Rankine power conversion
- 800 K composite radiators with Na or K heat pipes

Tether Propulsion

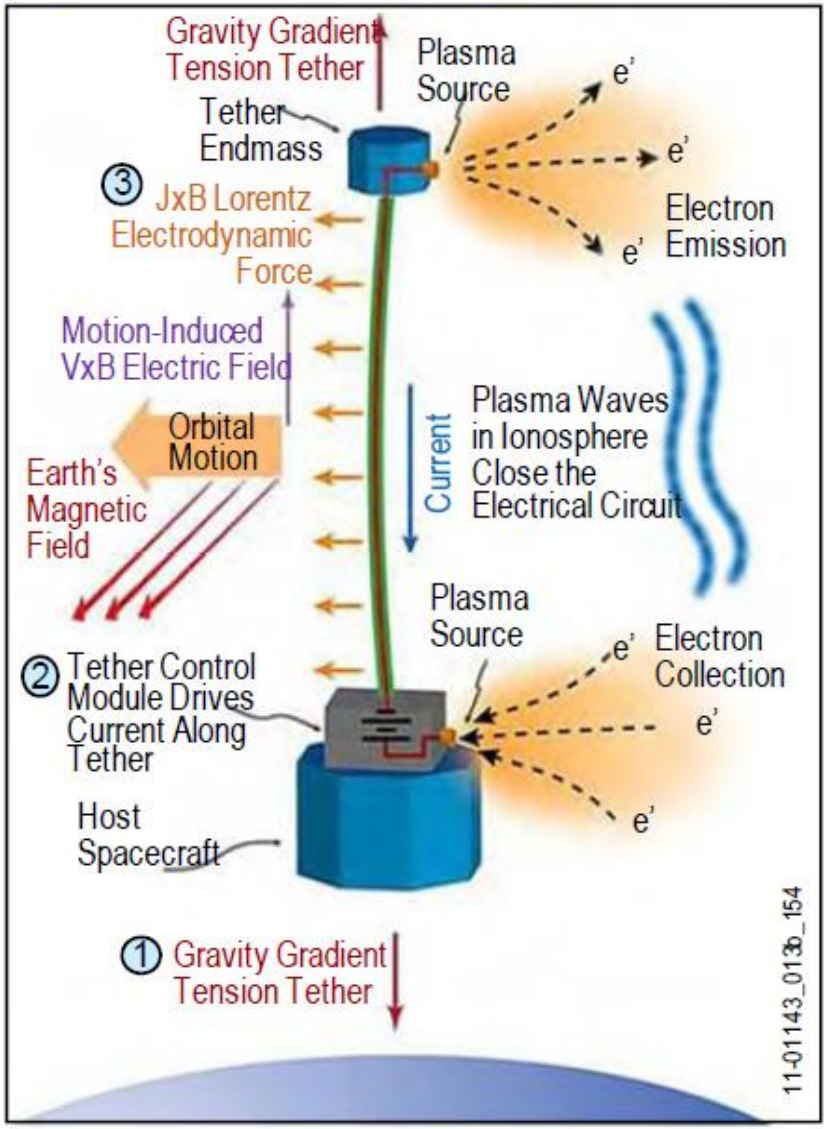


How Do ED Tethers Work?



An **Electrodynamic Tether (EDT)** is essentially a long conducting wire extended from a spacecraft. Gravity will tend to orient the tether in a vertical position. If the tether is orbiting around the Earth, it will be crossing the Earth's magnetic field lines at orbital velocity (7-8 km/s). The motion of the conductor across the magnetic field induces a voltage along the length of the tether.

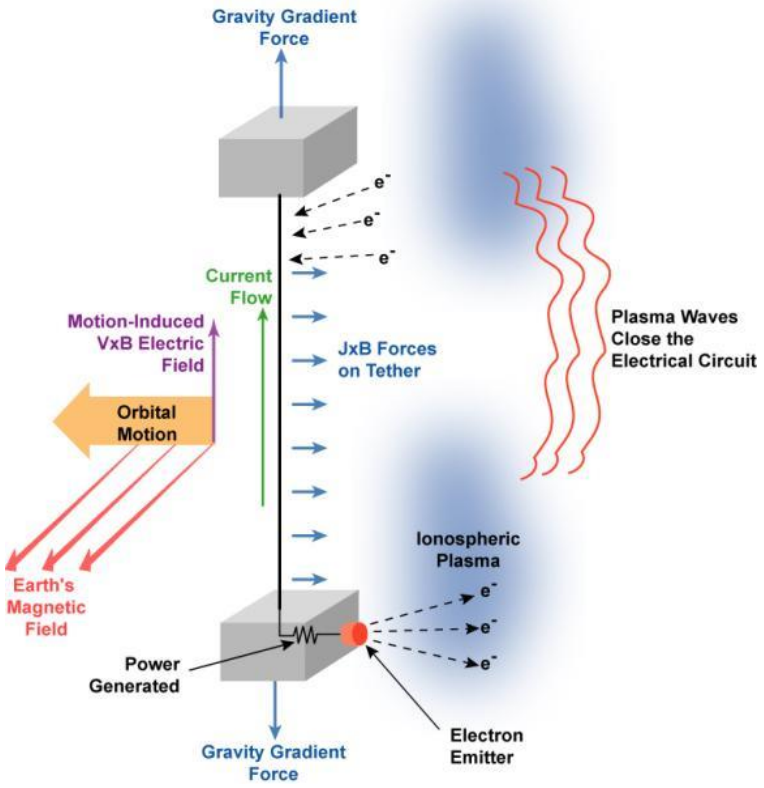
EDT Propulsion Fundamentals



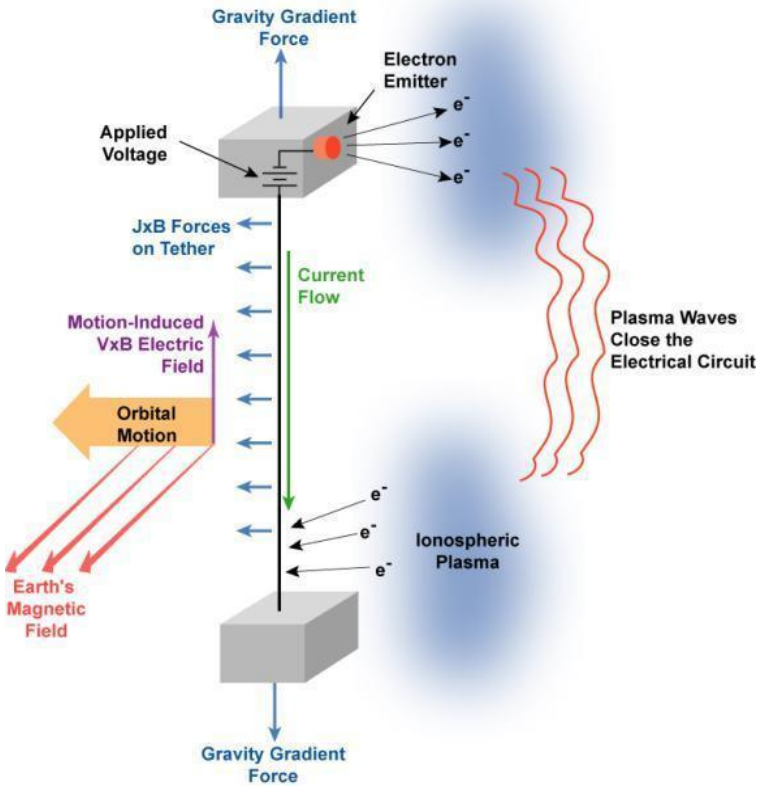
An electrodynamic tether generates thrust using interaction between current driven along a tether and a planet's magnetic field, enabling propulsion without propellant.

EDT Operational Modes

Deboost/Power Generation Mode

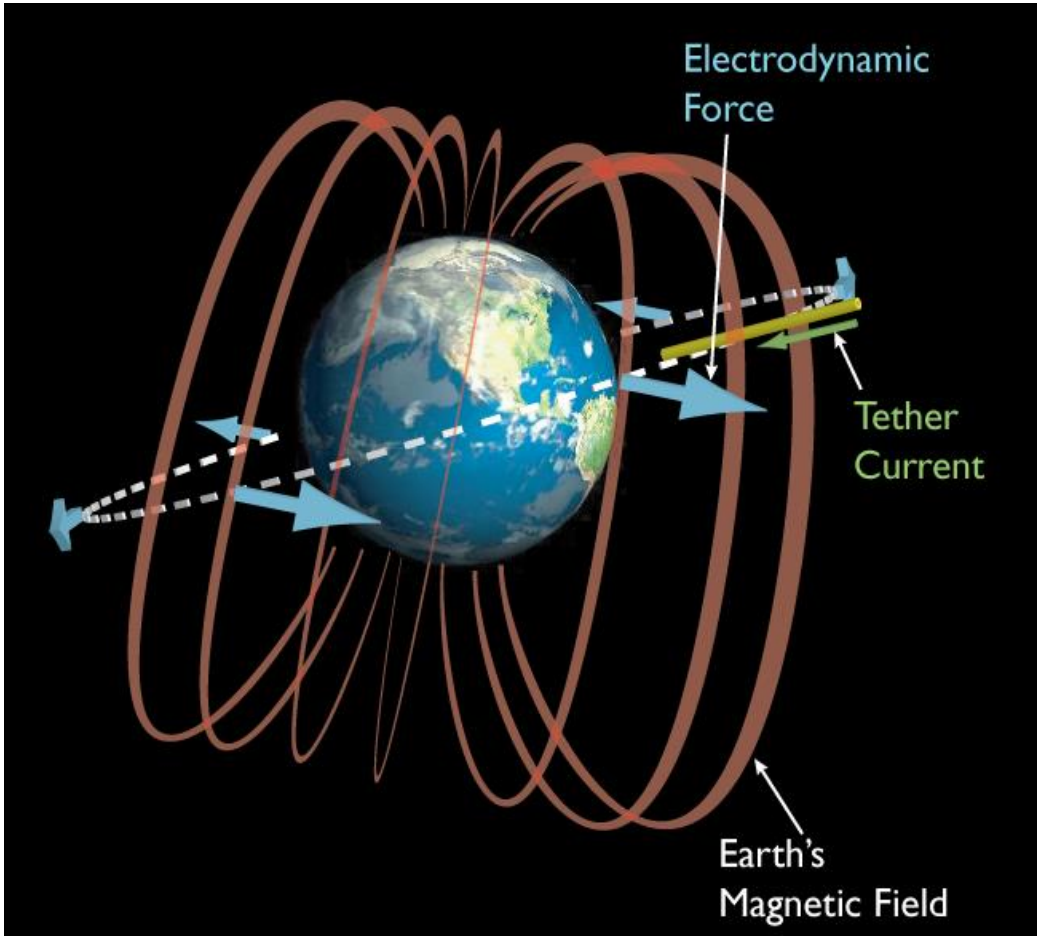


Boost Mode

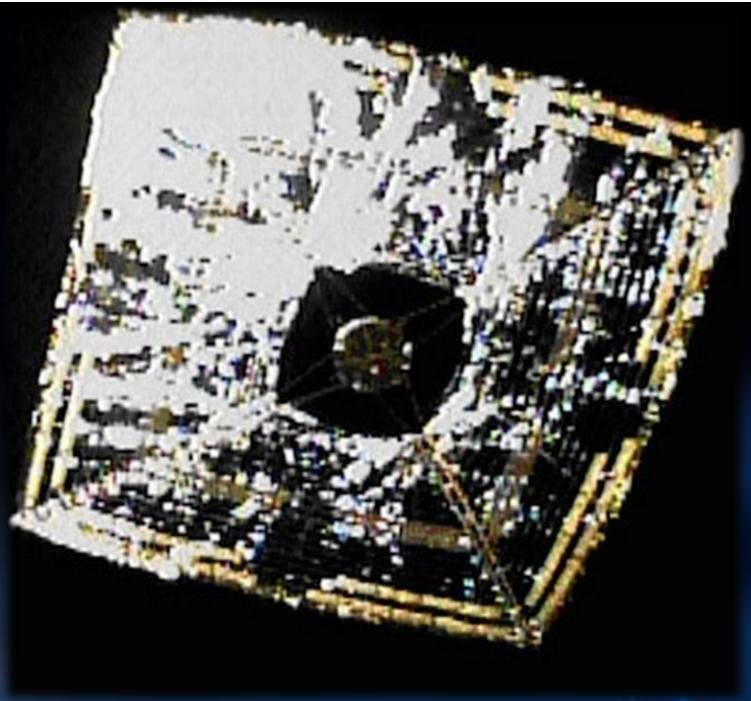


EDT Orbit Modification

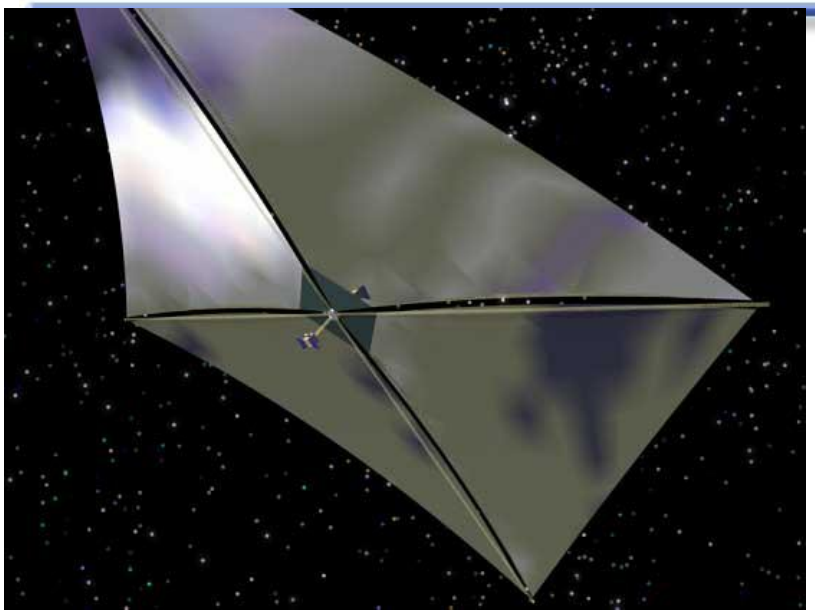
- Magnetic field strength and direction varies over each orbit
- Electrodynamic forces vary in an orbit
- Forces have components both:
- In-plane (orbit raising/lowering)
- Out-of-plane (inclination change)
- Tether current can be modulated over one or more orbits to change all six orbital elements



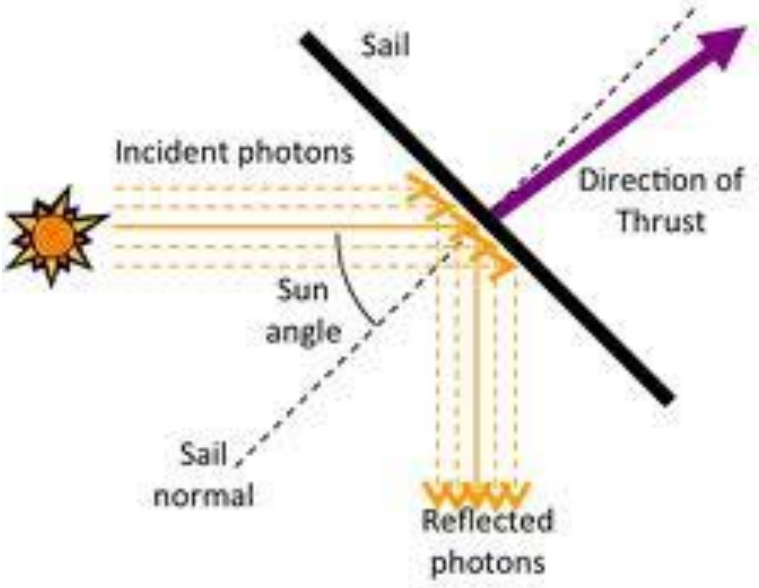
Solar Sail Propulsion

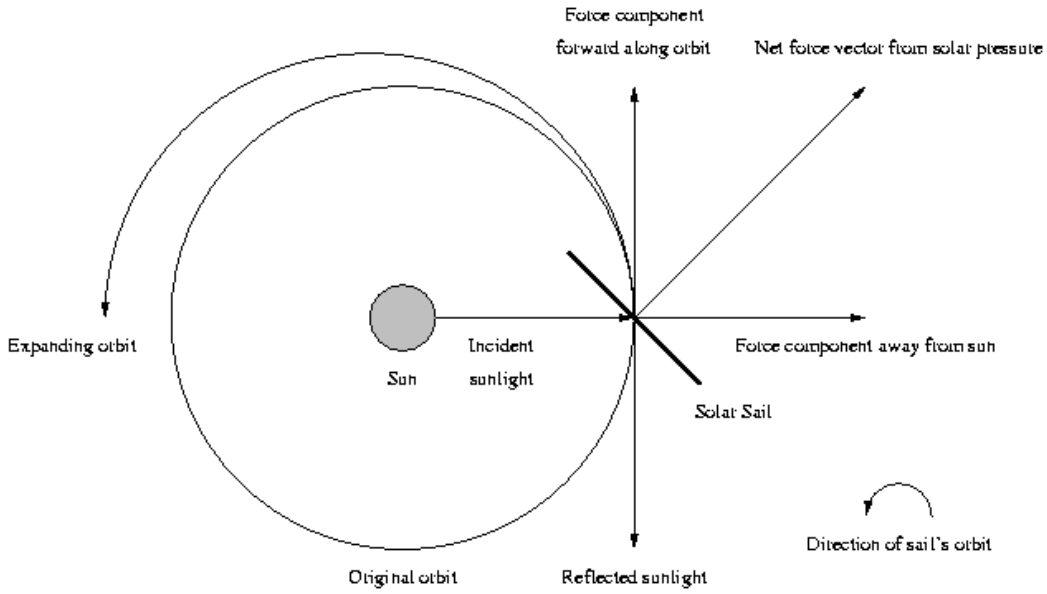


How does a solar sail work?

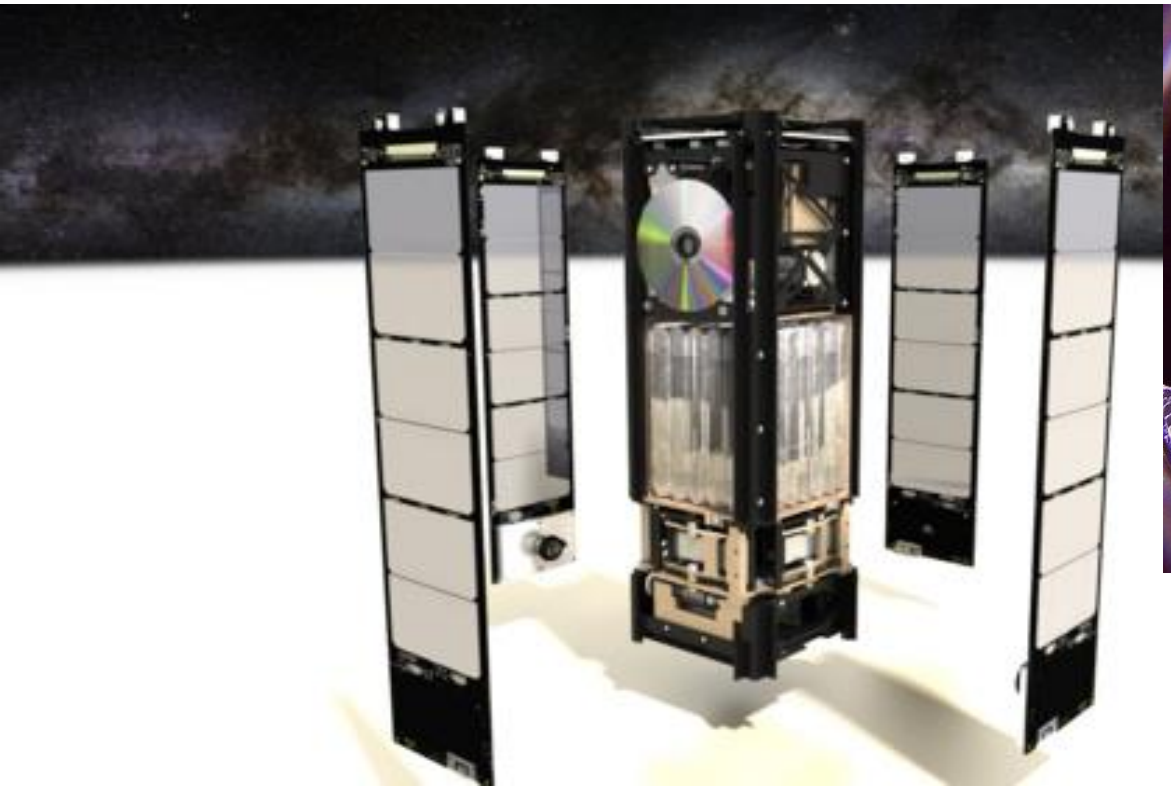


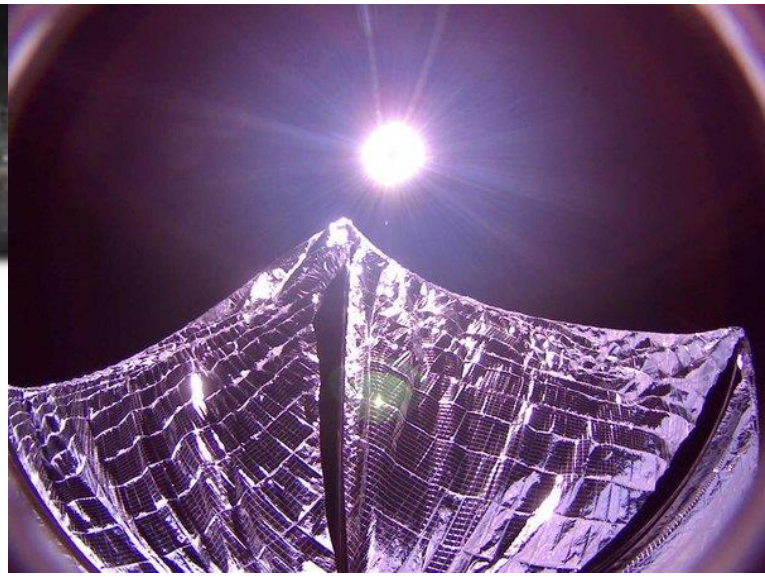
Solar sails use photon "pressure" or force on thin, lightweight reflective sheet to produce thrust.





LightSail-A and -2 (The Planetary Society)





- 3U Cubesat design
- Sail Material: aluminized 4.5 micron Mylar film
- 32 square meters solar sail area fully deployed
- LightSail-A (2015) and LightSail-B (2018)

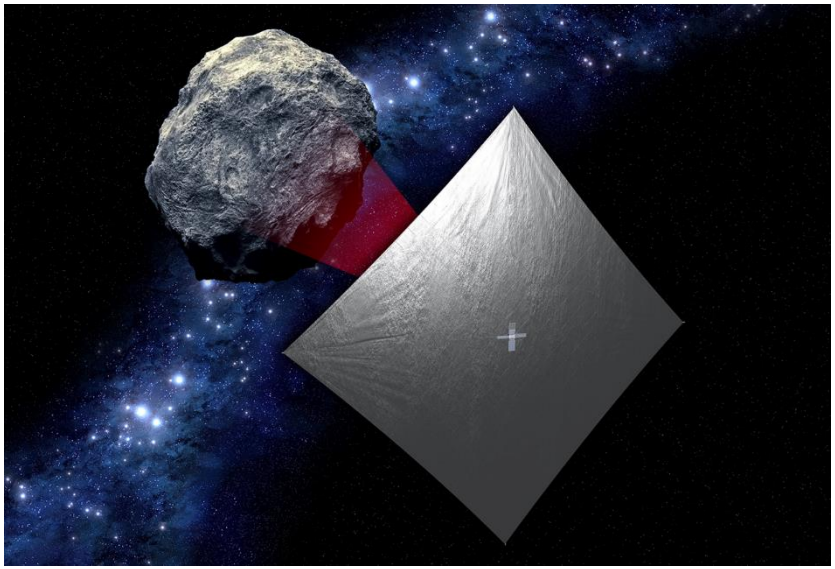
Near Earth Asteroid Scout

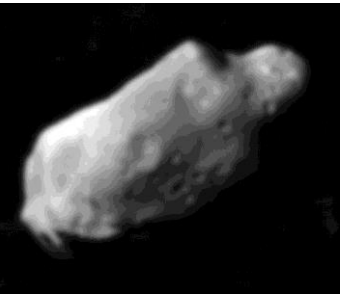
The Near Earth Asteroid Scout Will

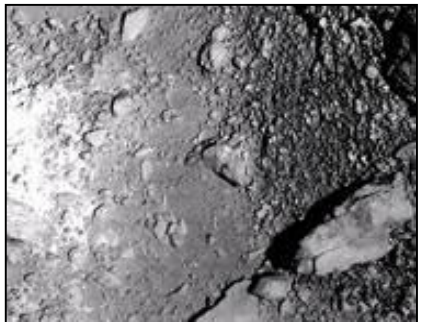
- Image/characterize a NEA during a slow flyby
- Demonstrate a low cost asteroid reconnaissance capability

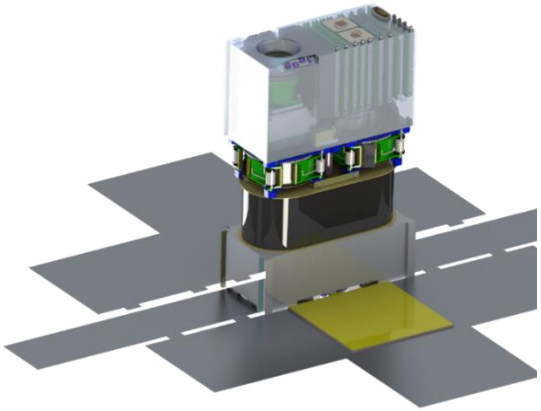
Key Spacecraft & Mission Parameters

- 6U cubesat (20cm X 10cm X 30 cm)
- ~86 m^2 solar sail propulsion system
- Manifested for launch on the Space Launch System (EM-1/2019)
- 1 AU maximum distance from Earth

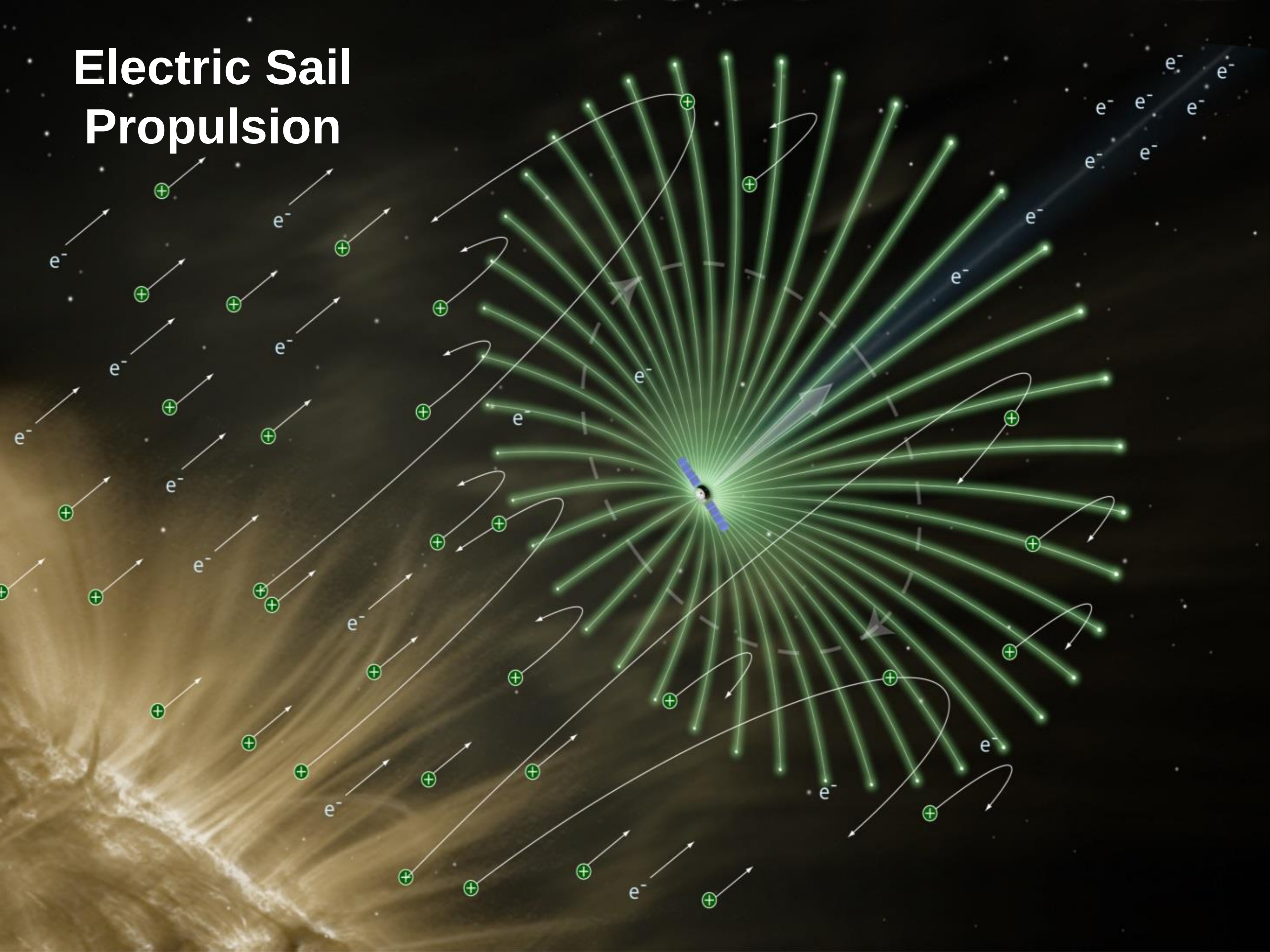




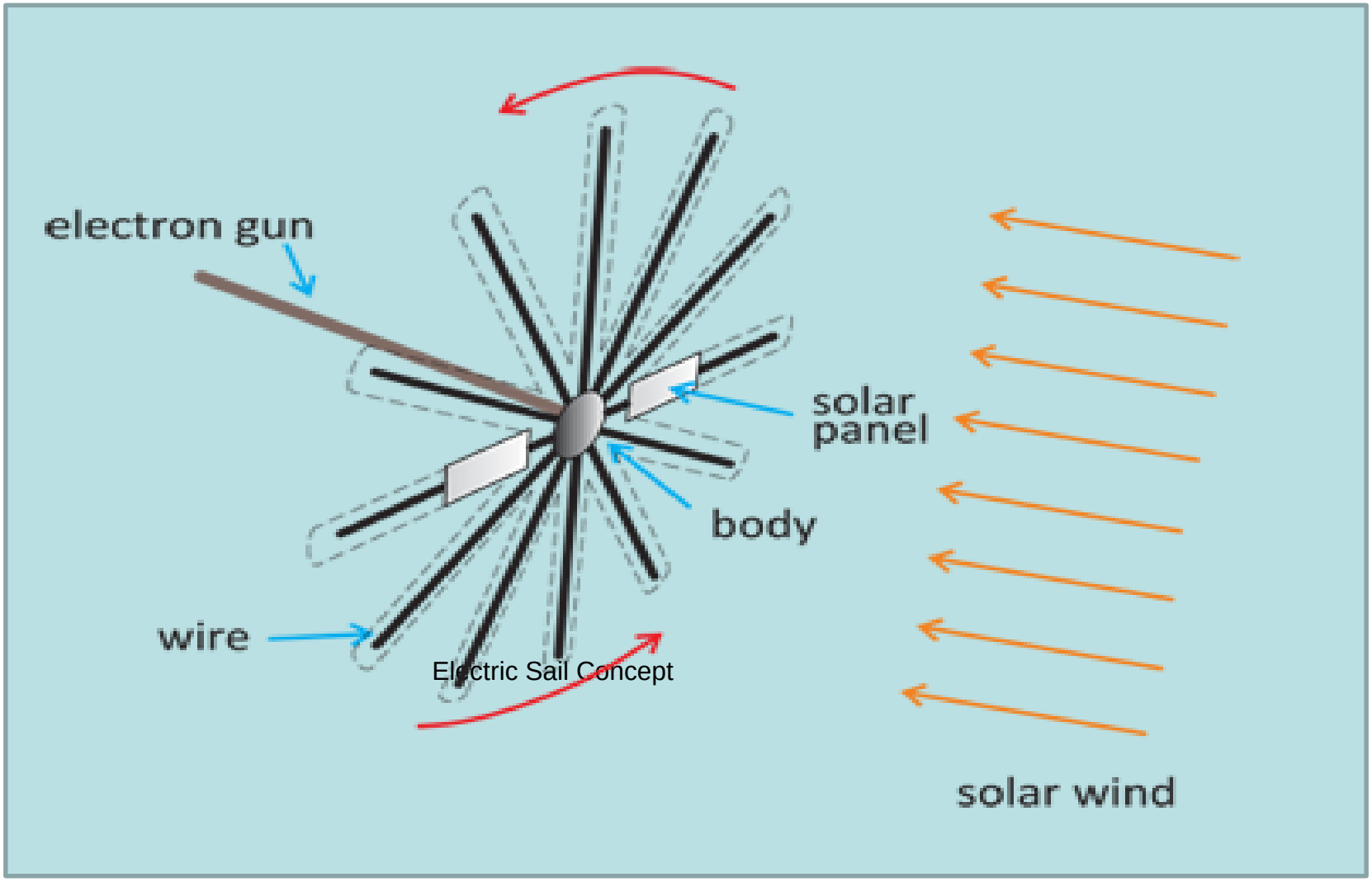




Electric Sail Propulsion



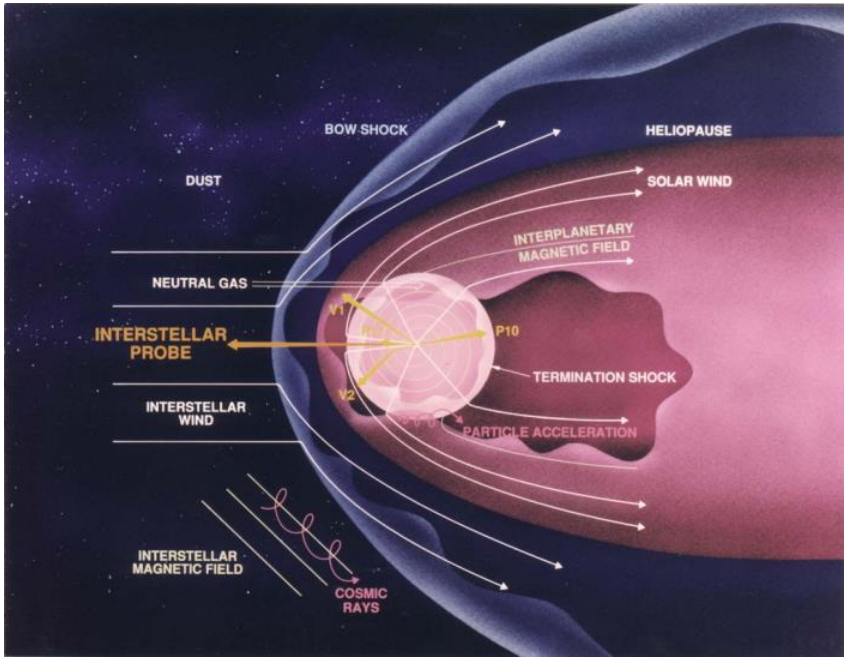
Electric Sail Propulsion Physics



Electric Sail Concept

THE FUTURE: Interstellar Probe

- A mission to beyond the Heliopause
  - –250 AU minimum
  - –Reach 250 AU within 20 years from launch
  - –15-20 AU/year target velocity
- Solar Sail Propulsion
- 500 meter diameter sail
- 1 - 5 g/m^2



The Heliopause is a barrier where charged particles from the sun cannot go beyond because cosmic rays from deep space force them back.

Propulsion Systems That Won't Work for Interstellar Voyages

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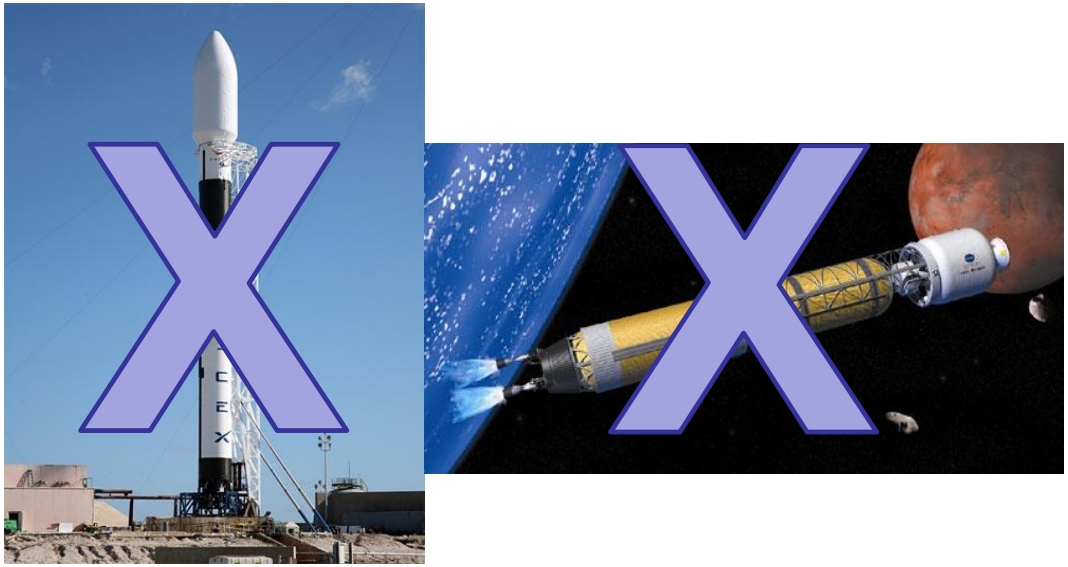
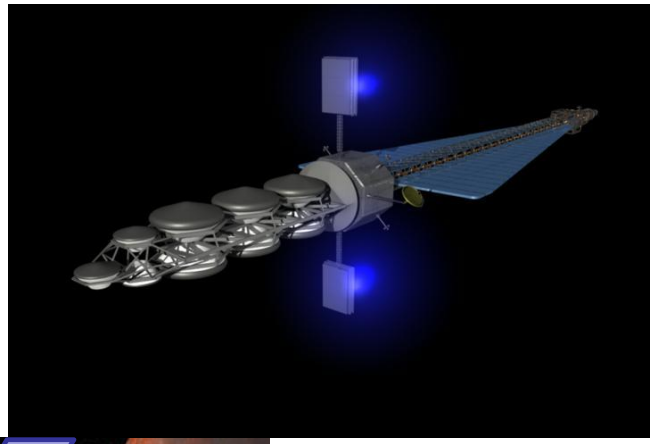
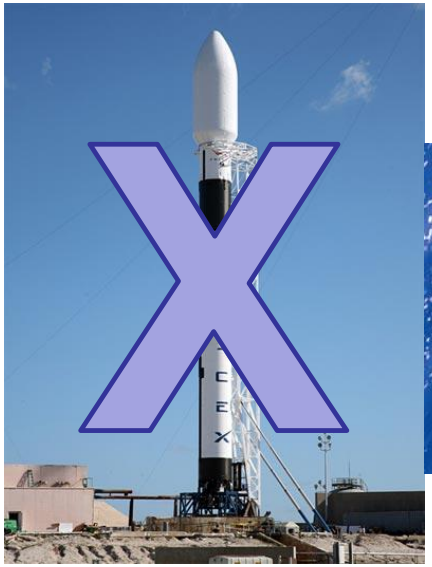
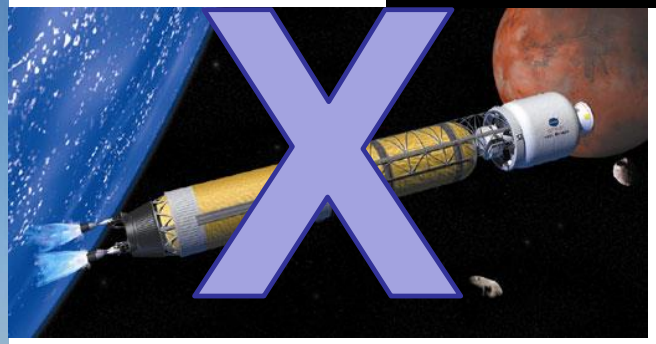


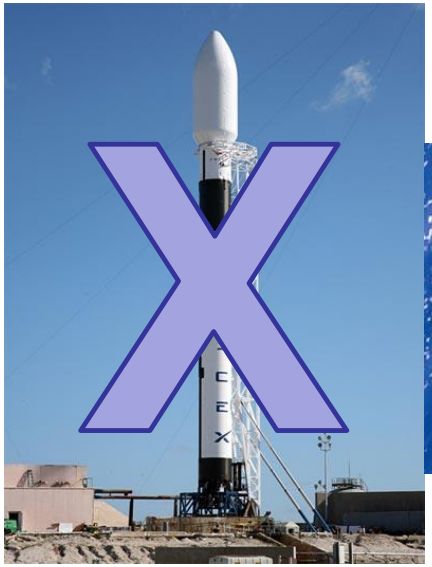
Propulsion Systems That Won't Work for Interstellar Voyages

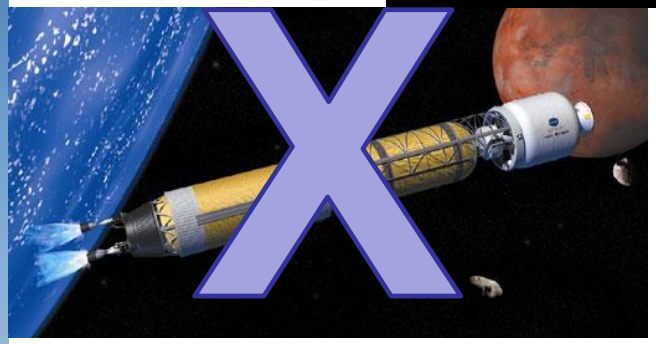




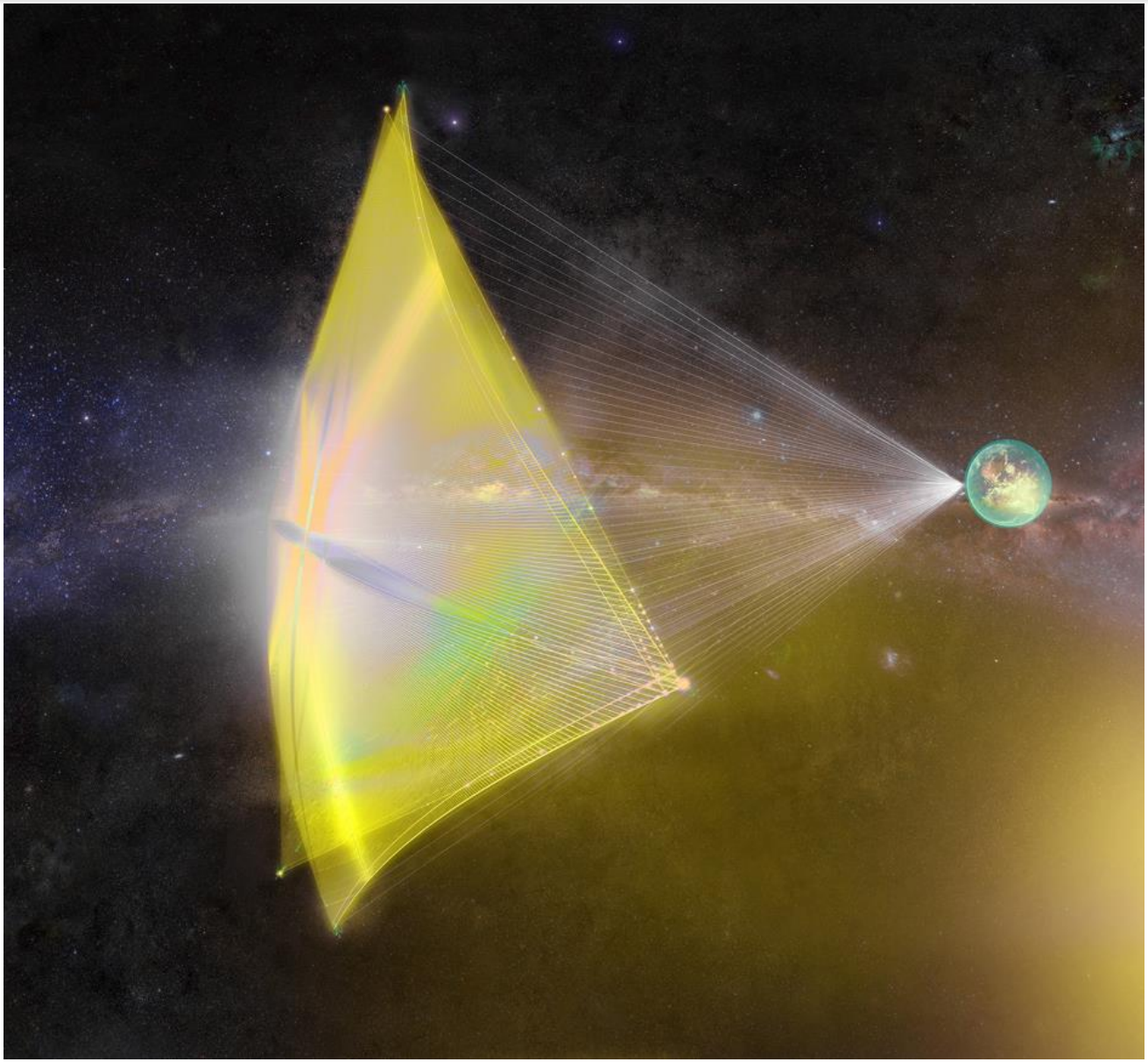


Propulsion Systems That Won't Work for Interstellar Voyages

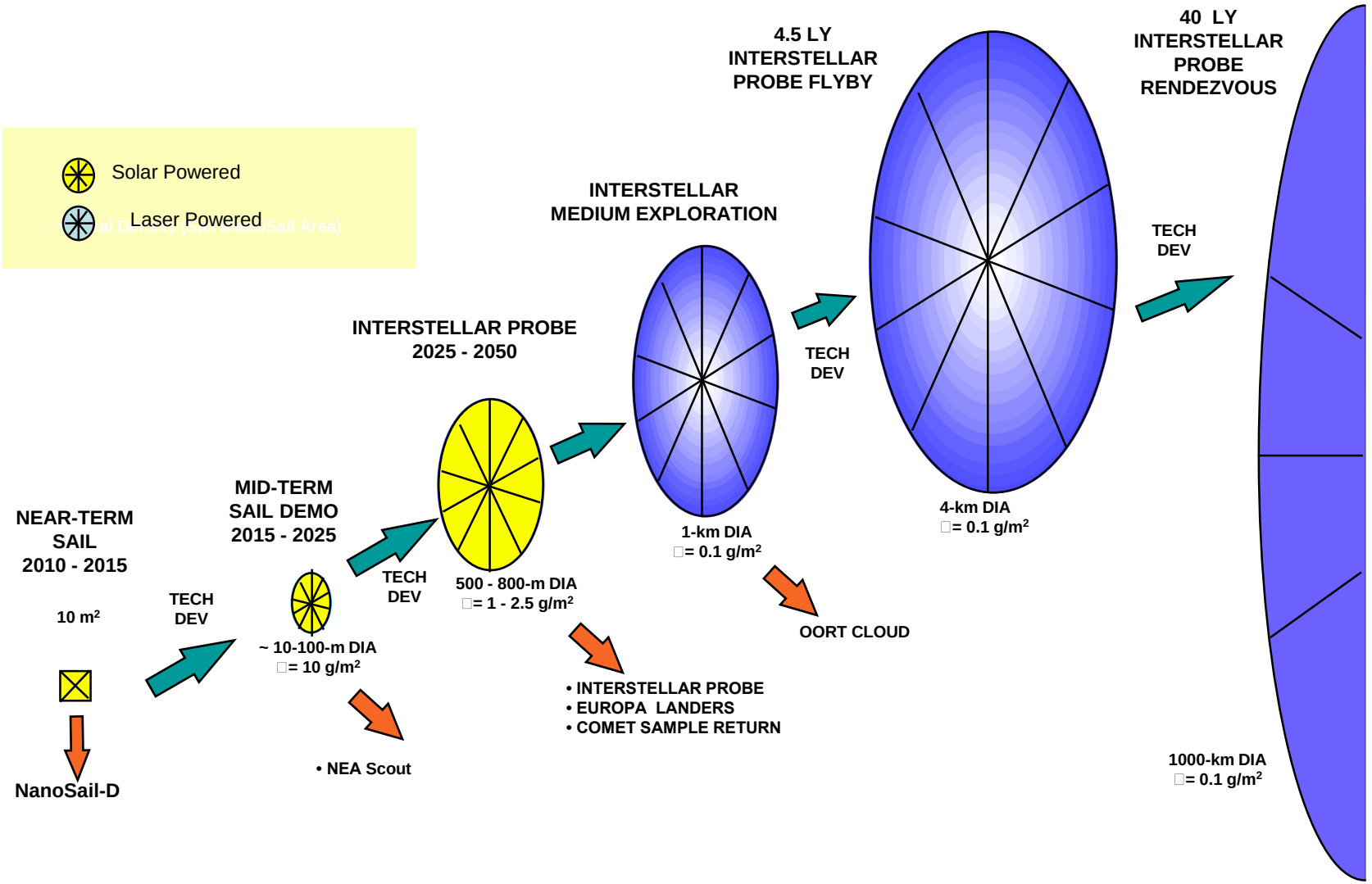




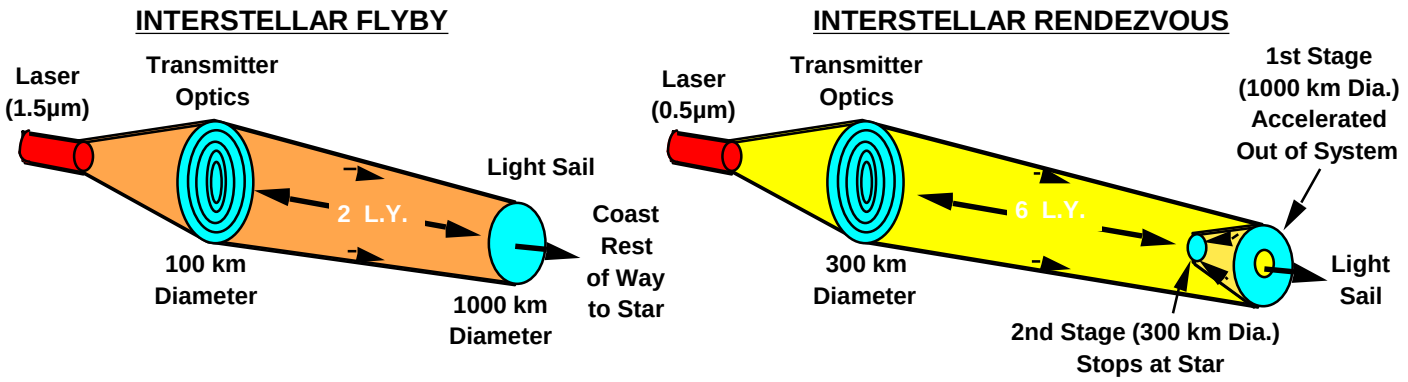
Solar and Laser Sails



Near-Term Solar Sail Applications Lead to Interstellar Capability with Laser Sails

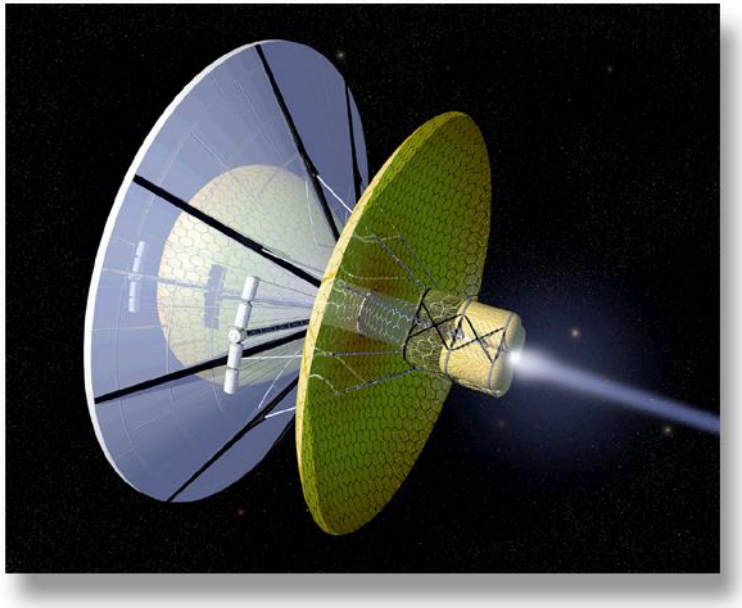


Interstellar Light Sail Concept

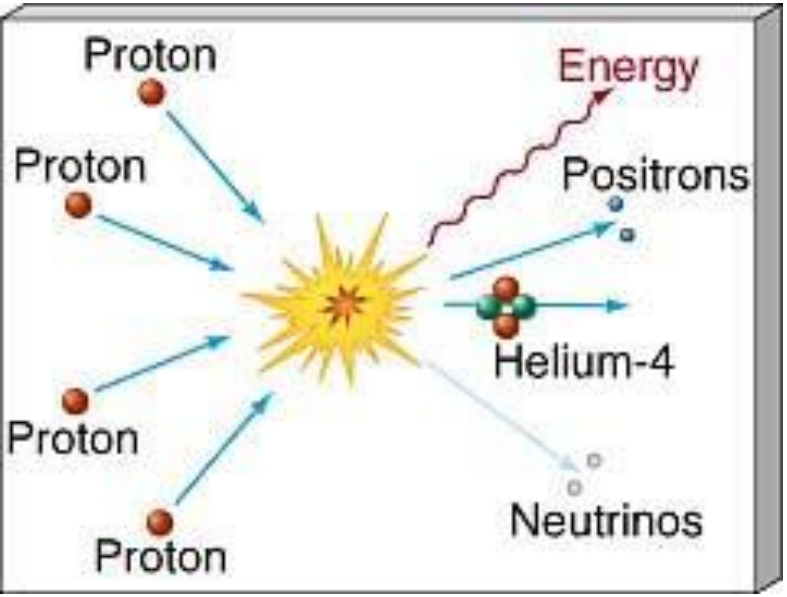


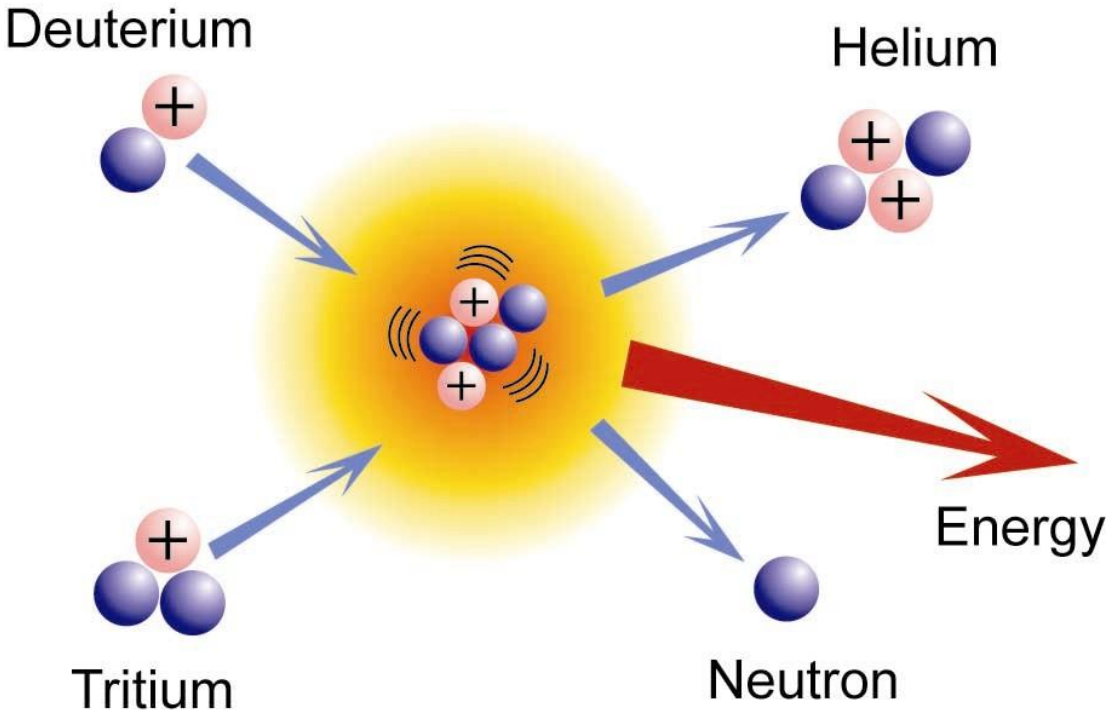
- **Advantages**
  - Perform interstellar missions in 50 - 100 years
  - Use as a solar sail once in orbit about target
  - Use solar power satellite as driver for robotic flybys
- **Disadvantages**
  - Very high laser / microwave powers (0.1-1,000 TW)
  - Very large optics (100-1,000 km)
- **Far-term concept, but one of the few ways to do "fast" interstellar missions**

Nuclear Fusion Propulsion

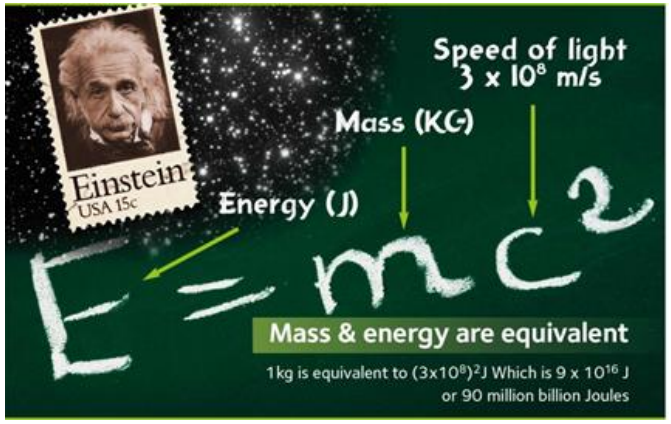


- Fusion propulsion will enable human exploration beyond Mars to the moons of the outer planets and perhaps, the stars
- Energy produced by the fusing of two hydrogen isotopes into helium - with the resulting energy release



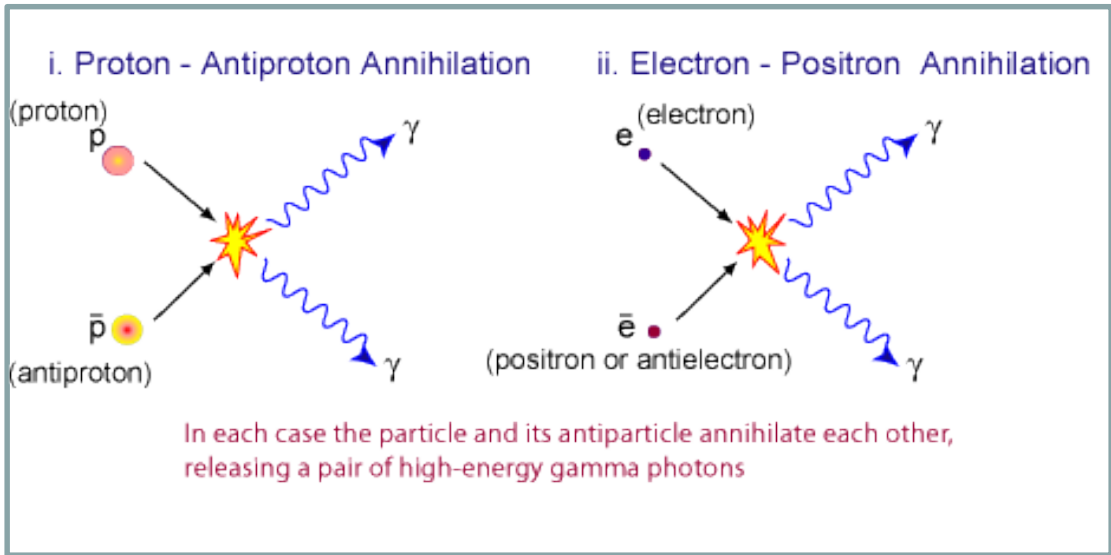


Antimatter Propulsion

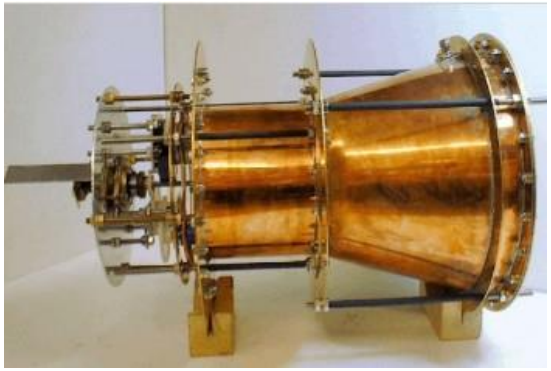


10 milligrams of antimatter is the energy equivalent of 120 tons of conventional rocket fuel

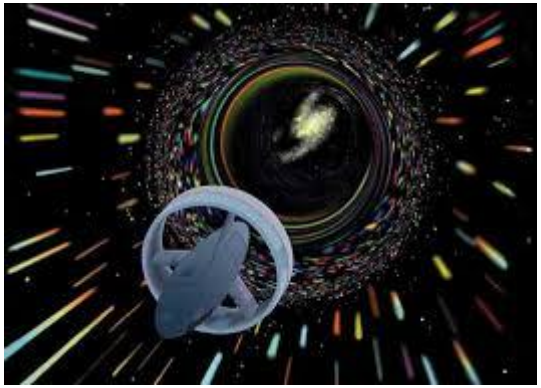
- As you learned from watching Star Trek, antimatter is real
- Matter and antimatter annihilate producing energy



Other ideas – *not necessarily real*

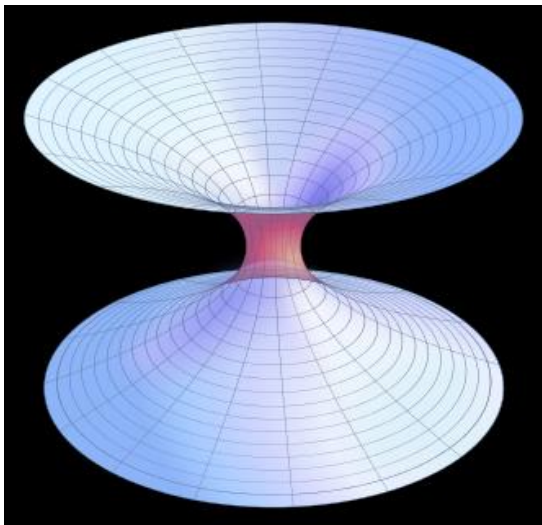


EmDrivE



Alcubierre Warp Drive

Wormholes



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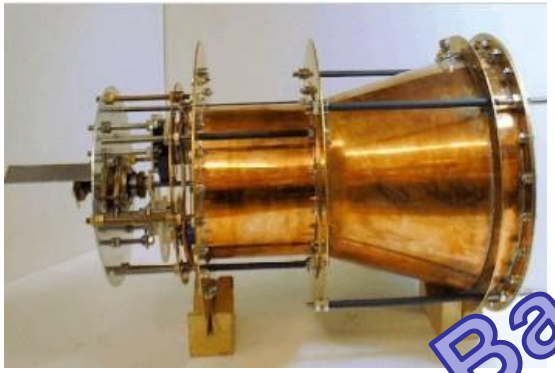
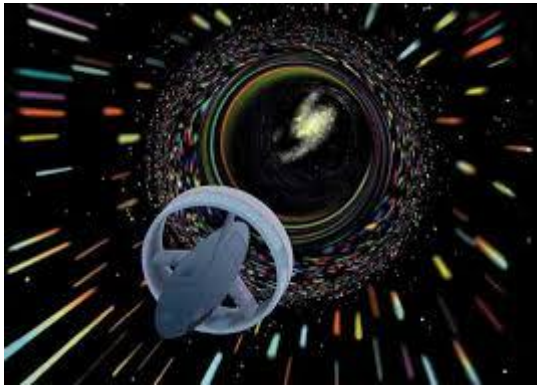


EmDrivE

Based on Speculative Physics



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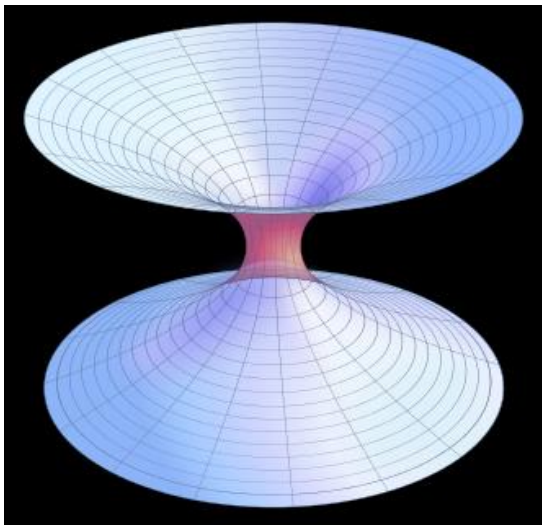

Congratulations!